ESF-POLATOM Exchange Visit Grant 5052

Scientific Report

Visitor: Dr. Mathieu Beau
Dublin Institute for Advanced Studies,
10 Burlington Road, Dublin 4, Ireland
mathieu.beau.89@gmail.com

Host: Prof. Adolfo del Campo
Department of Physics, University of Massachusetts,
Boston, 02125, MA, USA
adolfo.delcampo@umb.edu

Proposal Title: Full Tunneling Decay Dynamics of Atom-number States

Application Reference: 5052

1. Purpose of the visit

As mentioned in the proposal submitted in February 2015, the purpose of the visit was to characterize the full tunneling dynamics of many-body systems with interactions. To this end, during the stay at the University of Massachusetts Boston, I became familiar with the Calogero-Sutherland model of interacting particles trapped in a time-dependent harmonic potential [1,2]. The resonant state expansion formalism illustrates that the long time behavior in tunneling decay is governed by the low-momentum asymptotics of the retarded Green function, which motivates the study above. A recent article has been submitted by Prof. Adolfo del Campo (host) [3] where the multiparticle survival probability of the atom-number ground state of the Calogero-Sutherland gas was computed explicitely. This allows us to understand the effect of the interactions and the number of particles during all stages of evolution and in particular during the short and long-time decay. Following this idea, we have pursued the extension of these results to nonunitary dynamics resulting from coupling the system to a thermal bath. The main goal of such a model is to study the decoherence of a multiple-particle system with interactions, manifestedly a challenging problem. Even at the single-particle level, the long-time asymptotic behavior of quantum decay under Brownian dynamics has only been recently reported [4]. This project has also many applications such as atom counting statistics, preparation of atomic systems, and tunneling decay.

In parallel, we worked on another project on finite time quantum thermodynamics, which required similar mathematical tools. Besides the abundant literature on this topic [5-9], current experimental efforts [7,8] target the implementation of a quantum heat engine using ion traps. This work was done in collaboration with Prof. Adolfo del Campo and Dr. Juan Jamillo (long-term visitor), and will give rise to a publication in a month after the end of the visit.

2. Description of the work carried out and of the main results obtained during the visit

The first part of the visit was devoted to study the Calogero-Sutherland and the Caldeira-Leggett models. Then, we focused on computing survival and transition probabilities between excited states of a single-particle in a time-dependent harmonic trap coupled to a thermal bath. We found a general method to treat the problem and obtained promising results in what concerns the short and long-time quantum decays. Afterwards, our goal was to extend our method to the multiple-particle in a time-dependent harmonic trap coupled to a thermal bath. Depending on further progress along this line, a publication might result in the coming months.

Subsequently, we focused on the formulation and analysis of a paradigmatic model of a multiple-particle quantum engine. We carried out an in-depth analysis of the effect of the number of particle, strength of interactions on the optimal work and efficiency of the engine. Additionally, we introduced a finite-time driving protocol which is also relevant for shortcut to adiabatic expansion and compression processes, and that can be implemented with well-established technology in a variety of quantum platforms including ultracold atoms, trapped ions, and Bose-Einstein condensates.

The last month of my visit was devoted to writing reports to gather our results we obtained for the two projects. Then, we started to write an article about quantum thermodynamics that we expect to submit by the end of August.

3. Future collaboration with host institution

The visit will be extended until the end of November. The rest of the visit will be organized as follows. We will pursue our research on quantum decay with the objective of formulating a versatile model of multiple-particle system coupled to a thermal bath. Meanwhile, we planned to start a new project on shortcut to adiabaticity for spin systems. This will be a joined collaboration with Prof. del Campo's group.

4. Projected publications

As I mention previously, we expect to submit for publication the article on finite-time quantum thermodynamics by the end of August 2015. We also plan on working on three research projects (multiple-particle quantum decay, finite-time quantum thermodynamics and shortcut to adiabaticity for spin systems), which are expected to subsequently result in future publications. The European Science Foundation will be acknowledged in all the articles resulting from this visit.

5. Other comments

To conclude, this visit was very fruitful and productive as concerns scientific results and future publications of research articles. We have brought original contribution and new insight on the quantum thermodynamics and on survival probability. In addition, we have started new projects and established a future collaboration with the Quantum Science and Technology group of the University of Massachusetts, Boston.

References:

[1] F. Calogero, J. Math. Phys. 12, 419 (1971).

[2] B. Sutherland, J. Math. Phys. 12, 246 (1971).

[3] A. del Campo, http://arxiv.org/abs/1504.01620

[4] D. J. Bedingham, J. J. Halliwell Phys. Rev. A 89, 042116 (2014)

[5] M. O. Scully, Phys. Rev. Lett. 88, 050602 (2002).

[6] B. Lin and J. Chen, Phys. Rev. E 67, 046105 (2003).

[7] O. Abah, J. Roßnagel, G. Jacob, S. Deffner, F. Schmidt-Kaler, K. Singer, and E. Lutz Phys. Rev. Lett. **109**, 203006 (2012)

[8] J Roßnagel, O. Abah, F. Schmidt-Kaler, K. Singer, and E. Lutz Phys. Rev. Lett. **112**, 030602 (2014)

[9] J Roßnagel, K N Tolazzi, F Schmidt-Kaler and K Singer New J. Phys. **17** 045004 (2015).